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INCENDIARY GUNFIRE EVALUATION OF A CONDENSATE-FORMED FUEL FOG INERTING SYSTEM

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Army aircraft are vulnerable to catastrophic fuel tank explosions from incendiary impacts in the ullage. Previous testing indicated that aircraft fuel tank inerting concepts that create overrich ullage atmospheres should have a high probability of success. Nevertheless, initial attempts to design such a system using fuel fog techniques met with failure. Subsequently, a unique condensate-formed fuel fog system was tested under Contract DAAJ02-73-C-0087 and found to be effective in preventing ullage explosions caused by an electric match. After completion of the contract, the system was tested further and found to be ineffective in preventing fires initiated by an incendiary gunfire simulator.

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Prior to further development, however, this inerting system must demonstrate effectiveness against the incendiary threat encountered on the battlefield. The testing described herein is a ballistic evaluation of a condensate-formed fuel fog inerting system considered for application to Army aircraft. The system showed that it could prevent ullage explosions initiated by electric match; however, each incendiary impact resulted in a potentially catastrophic explosion. It is recommended that the concept not be considered for further development.

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INTRODUCTION

Army aircraft operate in close support of combat troops and consequently are exposed to a wide variety of hazards. In order to increase the operational suitability of Army aircraft, every effort is made to maximize their battlefield survivability. This report describes some work done to reduce the possibility of fuel tank explosions caused by incendiary ignition of the flammable vapors in the ullage.

The existence of the hazard depends on whether or not the basic requirements for the combustion process exist. Simply stated, a combustible material must come in contact with an ignition source in the presence of sufficient oxygen to support the process. In a closed container such as a fuel tank, an explosion will occur only when the ignition source is introduced into the tank which contains a suitable ratio of vaporized fuel to air. Initially it was assumed that Army aircraft would not be prone to fuel cell explosions because they use high volatility JP-4 fuel and normally operate in temperate or tropical climates such that the ullage atmosphere would always be above the normal static equilibrium flammability limits. A test program described in USAAVLABS TR 70-43[1] indicated that because of dynamic environmental flight conditions, flammable fuel/air mixtures do exist in Army aircraft fuel tanks for most mission profiles. Further experimental work reported in USAAMRDL TR 71-48[2] demonstrated that an incendiary projectile could initiate potentially catastrophic explosions of fuel/air vapor containers.

Therefore, systems to inert the ullage to incendiary ignition were considered for application to Army aircraft.

Testing indicated that inerting techniques that create an overrich mixture in the ullage should be successful. Incendiary ignition tests reported in Reference 2 indicated that the upper explosive limit of JP-4 was lowered from 8.1% JP-4 by volume to 3% when an incendiary ignition source rather than the classical spark ignition source was used. In addition, overrich mixtures should be fairly easy to achieve with JP-4 fuel. Fuel fog was one of the first such overriching inerting techniques considered. The fog system would consist of one or more nozzles located within the fuel tank to spray fuel recirculated by a small pump throughout the ullage. The penalties in weight, loss of usable fuel, maintenance, and cost should be very low.

It was recognized that in order for the fuel fog to have an inerting effect, droplets on the order of one micron in size must be created so that they would in fact act like a vapor. Larger droplets act as small ignition sites and reinforce the ignition. Therefore,

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[1] T. C. Kovic, N. L. Helgeson, and B. P. Breen, *Flight Vibration and Environmental Effects on Formation of Combustible Mixtures Within Aircraft Fuel Tanks*, USAAVLABS TR 70-43, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, September 1970, AD 875901.

[2] Charles M. Pedriani, *Experimental Determination of the Ignition Limits of JP-4 Fuel When Exposed to Caliber .30 Incendiary Projectiles*, USAAMRDL TR 71-48, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, July 1971, AD 730343.

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1. Kosvic, T. C., Helgeson, N. L., and Breen, B. P., *Flight Vibration and Environmental Effects on Formation of Combustible Mixtures Within Aircraft Fuel Tanks*, USAAVLABS TR 70-43, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, September 1970, AD 875901.

2. Pedriani, Charles M., *Experimental Determination of the Ignition Limits of JP-4 Fuel When Exposed to Caliber .30 Incendiary Projectiles*, USAAMRDL TR 71-48, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, July 1971, AD 730343.

3. Wiggins, E. W., and Malmberg, Q. C., *Aircraft Fuel Tank Inerting by Means of Fuel Cell Fuel Fogging*, AFAPL-6946, May 1969.

4. Laustsen, Russell, and Bristow, Robert, *Evaluation of Fuel Fog Inerting Concepts*, USAAMRDL-TR-74-13, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, April 1974.

the main parameters used to duplicate the test conditions. All tests were to be conducted at ambient conditions. After the appropriate test conditions were established, the match ignitor was activated to confirm the presence of an inerting effect. If no explosion occurred, the match ignitor was withdrawn and the tank was impacted with a caliber .30 incendiary projectile. The results were monitored with high-speed photography.

APPARATUS

A test tank capable of duplicating the test conditions used in Reference 4 was fabricated. The test tank itself was made from reinforced 1/4-inch-thick aluminum and measured 26 inches by 26 inches by 32 inches. It had side walls of 1/2-inch-thick Plexiglas® to facilitate photographic coverage of the combustion. A 1-foot-square blowout port was provided in the top.

Four standard oil burner nozzles, shown in Figure 1, were installed in the tank. They were rated at 1 gal./hr at 100 psig and had a 70° solid cone spray angle. The nozzles were located as shown in Figure 2. Two were used to supply fog at a temperature slightly below tank ambient and two to supply fog slightly above tank ambient. The nozzles were directed upward and into the tank to obtain maximum mixing. An electric heating tape was wrapped around the line supplying the "hot" nozzles, and a dry ice/alcohol bath was used to cool fuel for the "cold" nozzles. Thermocouples were positioned 1/8 inch in front of each nozzle and at the top and bottom of the tank to measure fog and ullage temperatures respectively.

Fuel fog flow rate could be controlled by regulating the pressure in the supply tank. During initial check-out tests, fairly stable (±1.5°F) fog temperatures were obtained by regulating the dry ice/alcohol bath and by intermittent use of the strip heater. In addition, several calibration tests were performed to establish the fuel fog flow rate as a function of supply pressure.

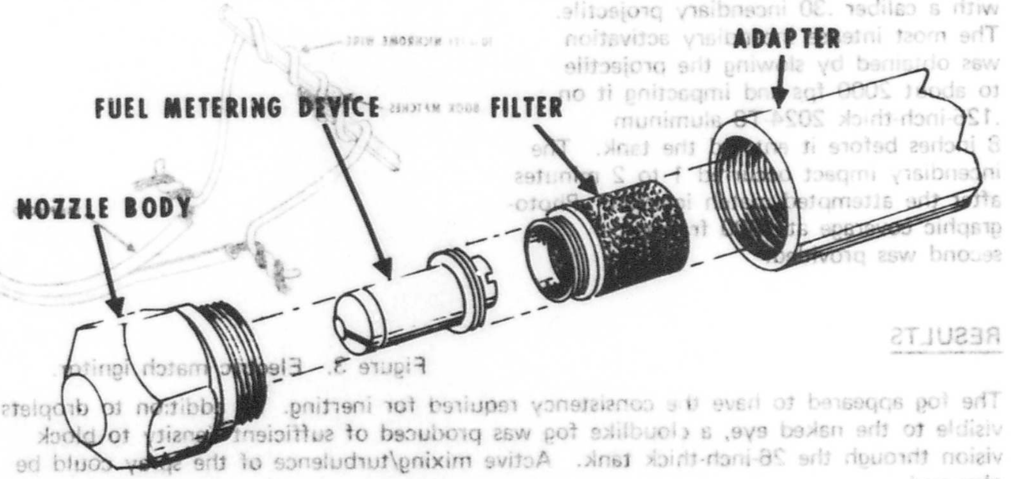

Figure 1. Fog nozzle.

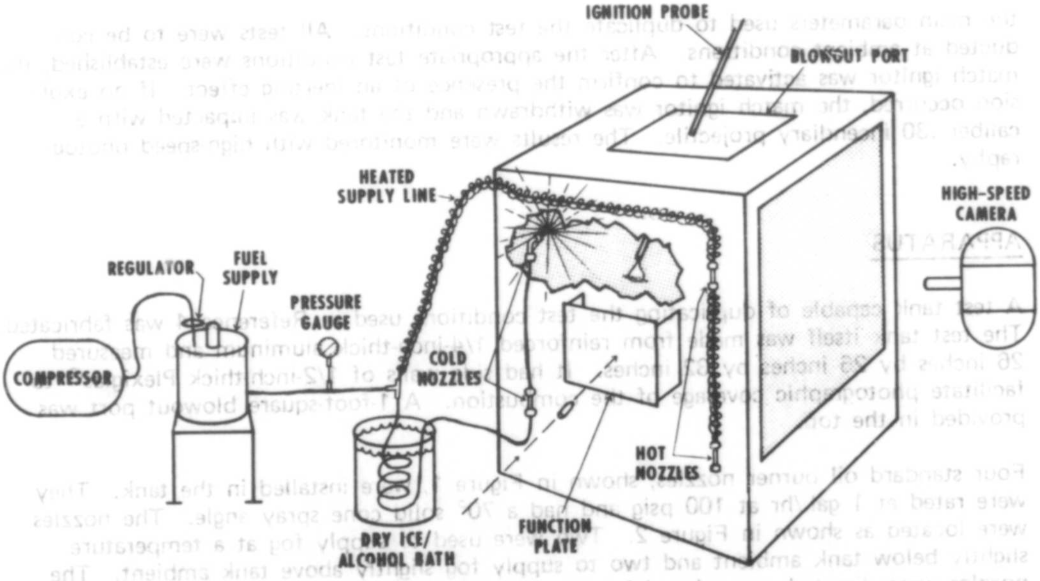

Figure 2. Test apparatus schematic.

PROCEDURE

The fog system was pressurized and the fog temperatures adjusted to the desired test values. All temperatures were allowed to stabilize for a minimum of 10 minutes prior to testing. Ignition was attempted with the electric match ignitor shown in Figure 3. If an explosion did not occur, the probe was withdrawn and the tank was impacted with a caliber .30 incendiary projectile. The most intense incendiary activation was obtained by slowing the projectile to about 2000 fps and impacting it on .125-inch-thick 2024-T3 aluminum 8 inches before it entered the tank. The incendiary impact occurred 1 to 2 minutes after the attempted match ignition. Photographic coverage at 1000 frames per second was provided.

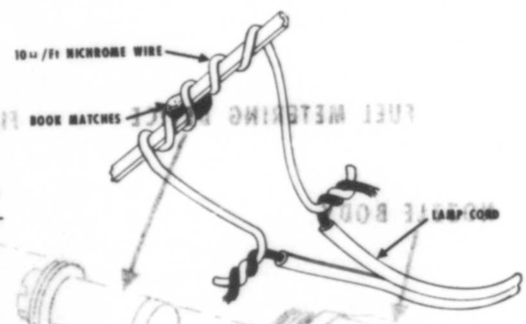

Figure 3. Electric match ignitor.

RESULTS

The fog appeared to have the consistency required for inerting. In addition to droplets visible to the naked eye, a cloudlike fog was produced of sufficient density to block vision through the 26-inch-thick tank. Active mixing/turbulence of the spray could be observed.

The test conditions and results are itemized in the table on page 8. The initial test results seemed to confirm the presence of a marginal inerting effect. Lack of complete inerting was attributed to the low fog flow rate. Tests reported in Reference 4 showed that a flow rate, C_F, of .33 gal./hr/ft^3 was required for complete electric match inerting, so the C_F was subsequently increased incrementally to .38 as shown in the table.

In summary, some success was achieved in inerting the ullage to ignition by electric match; however, every incendiary impact resulted in a potentially catastrophic explosion regardless of the test conditions.

The differences in the types of explosion caused by the match and incendiary were apparent in the high-speed photographic coverage. The point source match ignition was characterized by the propagation of a relatively slow moving spherical wave front. The incendiary, on the other hand, was characterized by ignition occurring over a large area very rapidly.

OBSERVATIONS

The question of why the system worked for a match and not for the incendiary cannot be answered here with certainty; however, several observations can be made. Prior to each incendiary exposure, it was demonstrated that the ullage atmosphere would not propagate a typical ignition wave. Therefore, either the incendiary impact itself altered the ullage atmosphere, or incendiary ignition does not depend on flame front propagation. The high-speed photographic coverage provides some evidence to support both of these explanations. First, the projectile passed through the tank above sonic velocity, exposing it to a shock wave, injecting air into the tank as it entered, and withdrawing ullage atmosphere as it exited. Naturally these forces tend to disrupt the inerting effect. Furthermore, the incendiary particles are introduced into the ullage in a cloud with numerous ignition locations, minimizing the requirement for flame front propagation.

CONCLUSIONS

The condensate-formed fuel fog inerting system has some inerting effect for an electric match ignition source. However, the system shows no potential for preventing ullage explosions initiated by incendiary projectiles.

RECOMMENDATION

The condensate-formed fuel fog inerting concept should not be considered for further development or application to Army aircraft.

SUMMARY OF TEST CONDITIONS AND RESULTS

Test Temperatures (°F)					
Ullage Ambient*	Hot Nozzles	Cold Nozzles	C_F**	Ignition Source	Results
66,69	70,71	51,55	.21	match	no fire
				cal .30 inc	fire
66,67	71,72	55,56	.21	match	fire
73,73	77,78	51,56	.21	match	no fire
				cal .30 inc	fire
76,77	80,81	56,62	.21	match	no fire
				cal .30 inc	fire
61,61	62,62	49,53	.21	match	no fire
				cal.30 inc	fire
65,66	65,66	50,55	.21	match	no fire
66,66	66,67	60,61	.21	match	no fire
67,68	67,68	64,64	.21	match	no fire
64,65	71,74	41,45	.21	match	fire
65,66	68,69	46,50	.21	match	fire
67,66	70,72	45,52	.21	match	fire
65,64	66,69	45,53	.26	match	no fire
				cal .30 inc	fire
65,66	68,70	45,55	.26	match	no fire
				cal .30 inc	fire
50,55	58,53	36,36	.38	match	no fire
				cal .30 inc	fire
61,61	72,67	46,49	.38	match	no fire
				cal .30 inc	fire
36,41	45,49	20,26	.35	match	fire
45,50	54,56	21,25	.35	match	no fire
				cal .30 inc	fire
48,46	54,54	29,29	.35	match	fire
52,53	59,60	36,38	.35	match	fire

*At two locations, top and bottom of ullage

**C_F = Total fuel fog flow rate per ullage volume – gal./hr/ft^3

REFERENCES

1. Kosvic, T. C., Helgeson, N. L., and Breen, B. P., *Flight Vibration and Environmental Effects on Formation of Combustible Mixtures Within Aircraft Fuel Tanks*, USAAVLABS TR 70-43, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, September 1970, AD 875901.

2. Pedriani, Charles M., *Experimental Determination of the Ignition Limits of JP-4 Fuel When Exposed to Caliber .30 Incendiary Projectiles*, USAAMRDL TR 71-48, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, July 1971, AD 730343.

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